# An Update of the Near-Earth Asteroid Tracking/Maui Space Surveillance System (NEAT/MSSS) Collaboration

**Raymond J. Bambery, Eleanor F. Helin, Steven H. Pravdo, Kenneth J. Lawrence, Michael D. Hicks**

*California Institute of Technology*
*Jet Propulsion Laboratory*
*Pasadena, CA 91109*

## 1. Abstract

Jet Propulsion Laboratory's (JPL) Near-Earth Asteroid Tracking (NEAT) program has two simultaneously-operating, autonomous search systems on two geographically-separated 1.2-m telescopes; one at the Maui Space Surveillance System (NEAT/MSSS) and the other on the Palomar Observatory's Oschin telescope (NEAT/Palomar). This paper will focus exclusively on the NEAT/MSSS system.

NEAT/MSSS is operated as a partnership between NASA/JPL and the United States Air Force Research Laboratory (AFRL), utilizing AFRL's 1.2-m telescope on the 3000-m summit of Haleakala, Maui. The USAF Space Command (SPCMD) contributed financial support to build and install the "NEAT focal reducer" on the MSSS telescope giving it a large field of view (2.5 square degrees), suitable for the near-earth object (NEO), both asteroids and comets, survey. This work was completed in February 2000. AFRL has made a commitment to NEAT/MSSS that allows NEAT to operate full time with the understanding that AFRL participate as partners in NEAT and have use of the NEAT camera system for high priority satellite observations during bright time (parts of 12 nights each month) [1]. As of September 1, 2002 NEAT has discovered 64 NEAs including 16 larger than 1-km, 11 Potentially Hazardous Asteroids (PHAs), 9 comets, and nearly 170,000 asteroid detections.

## 2. NEAT and NASA's Near-Earth Object Program

The objective of Near-Earth Asteroid Tracking (NEAT) Program is to discover Near-Earth Objects (NEOs) and to enable their further characterization. The NEO population consists of Near-Earth Asteroids (NEAs) and comets passing close to Earth. These discoveries are to fulfill the highest priority of NASA's NEO Observation Program which is "to primarily inventory the population of Near-Earth Objects and, secondarily, to characterize a representative sample of them." [2]. To put this into quantifiable terms, *it is to find > 90 % of Near-Earth Asteroids whose diameter is greater than 1 km by 2008.* [3]

NEAT discoveries contribute data for statistical studies of all asteroid classes, enable follow-up observations for physical characterizations including spectroscopy and radar, and identify candidates for space missions. In summary, the inventory aspect of the NEAT program addresses the question *"What are the population of objects that pass close to earth in the near-term?"* and the characterization, or science, addresses the question *"Is this population stable or are there mechanisms that continually replenish or drain this population which in turn could significantly modify the quantity and spatial distribution of NEOs in the long term?"*

NEAT currently operates with two autonomous search systems on two 1.2-m telescopes: (1) on the Maui Space Surveillance System, NEAT/MSSS, and (2) on the Palomar Observatory Oschin telescope, NEAT/Palomar. This report details recent results utilizing the NEAT/MSSS telescope. NEAT/MSSS is operated as a partnership between NASA/JPL and the United States Air Force Research Laboratory (AFRL), utilizing AFRL's 1.2-m telescope on the 3000-m summit of Haleakala, Maui. AFRL has made a commitment to NEAT/MSSS that allows NEAT to operate full time with the understanding that AFRL participate as partners in NEAT and have use of the NEAT camera system for high priority satellite observations during bright time (parts of 12 nights each month) [4].

## 3. History

JPL has collaborated successfully with the Air Force Maui Optical and Supercomputing (AMOS) site since 1993, when they performed follow-up observations of discoveries from Dr. Eleanor Helin's Palomar Planet Crossing Asteroid Survey [5] using their 1.6-meter telescope. The NEAT project developed a CCD camera and a set of automated detection software for a system that began operating in late 1995 on the Ground-Based Electro-Optical Deep Space Surveillance System (GEODSS) 1-m telescope at Haleakala, Maui. Helin [6] and Pravdo, et al.

[7] described the attributes and capabilities of that system. In the period from March 1996 to August 1998, NEAT/GEODSS searched approximately 35,000 square deg of sky and detected 45 NEAs, with 26 larger than 1 km. After the USAF Space Command funded a focal reducer, the NEAT camera was transferred to MSSS in March 2000. Like the GEODSS system before it NEAT/MSSS is autonomous and remotely directed from JPL [8].

NEAT/MSSS achieved its first light in March, 2000. Now, 30 months later, it is a mature system and is contributing significantly to discoveries of NEAs and comets. Last year at this conference, we reported that MSSS had discovered 27 NEAs and 6 comets from January to mid-August. We now report an additional 22 NEA's and 3 comets. More details of the discoveries of NEAT/MSSS are given in Section 11.

## 4. Hardware

The MSSS telescope used by NEAT is one arm of a twin-mounted 1.2-meter telescope. A focal reducer was developed by AFRL personnel to provide the wide 2.5-degree field of view needed for a survey instrument. Talent, et al. [8] describes the requirements. The NEAT/MSSS camera is installed at the prime focus and operates under pointing constraints of ±25 degrees in declination.

The current NEAT/MSSS camera consists of a 4096 x 4096 charge-coupled device (CCD) with 15-micron square pixels, camera electronics, 2 thermoelectric coolers, and a mechanical shutter. The CCD is a front-side illuminated, commercial-off-the-shelf part manufactured by Fairchild Imaging. It features good cosmetic quality and low dark current, with less than 0.3% of the area unusable due to blemishes. Four output nodes or amplifiers read out each quadrant in parallel. The read noise is about 20 electrons at a readout speed of 200 kpixels per sec. The bandpass is about 0.40-0.85 μm determined solely by the CCD response (i.e., no filters) and the optics. Using standard stars as calibrators, NEAT magnitudes are converted to *V* values with a precision of about 0.1 magnitudes.

## 5. NEAT Observing Strategy

A typical night of observation of NEAT/MSSS begins with uploading from JPL an observing script which determines telescope pointings, integration times and the time separation between repeat visits, typically fifteen minutes, of each search field. Follow-up observations of objects discovered on previous nights are often included. Observations begin after nautical twilight. Fields are taken sequentially from the script, with software keeping track of observations completed until three images of each search field is obtained. The automated data analysis begins during the night, processing each triplet as it is completed. Search fields are typically along the ecliptic, with avoidance zones ±15 degrees from the galactic plane and ±30 degrees from the Moon. The analysis software generates "patches", which are small 25 pixel sub-images centered about candidate moving objects. The patches are returned nightly to JPL to be used in post-processing.

## 6. Automated Near Real Time Object Detection

The NEAT asteroid detection algorithm depends on the temporal displacement of the moving object in a field of "fixed stars". Typical temporal separation is 15 to 20 minutes for each frame and the collection of 3 frames provides a compromise between maximizing sky coverage per night and minimizing failures in the detection process. Failures in the process include missed detections because of such things as changes in seeing in one of the frames or occultations of the asteroid with nearby stars. Failures are also caused by "false detections" due to artifacts in the image such as cosmic ray hits and internal reflections from bright off-axis stars in the telescope optics. Failures are minimized by filter steps in the real time data processing stream, as much as practicable, but are often only eliminated in visual inspection in post processing at JPL. To facilitate the latter step a tool, patchview, shown in Fig 4, analyzes the "patches" around the putative discoveries. Upon completion of this step, the astrometry of both the fast moving near-Earth objects and main-belt asteroids, which are based on USNO A2 catalog stars [9], are submitted to the Minor Planet Center (MPC).

## 7. Detection Limits and Sky Coverage

The limiting magnitude of a NEA detection system is a complex function of rates of motion, exposure time, sky background, seeing, etc., and can vary greatly even within a single night of observation. Periodically we calibrate system performance by imaging Landolt fields [10] as they transit but the most appropriate way to quantify the detection efficiency is to look at the magnitudes of our NEO discoveries. Fig. 1 plots the discovery magnitudes and rates of motion of the 64 Near-Earth asteroids and 9 comets found by the MSSS system over the past 30 months. The dotted line marks an approximate detection limit under exceptional conditions, with the system capable of going down to V=21 in a 60 sec. exposure for a stationary object or 19.5 for an object moving up to 5 degrees per day. A more typical detection limit (defined as an object having a 50% chance of being flagged as an NEO by the analysis software) would be V=19.7±0.3 for objects moving 2 degree per day or slower. This is a

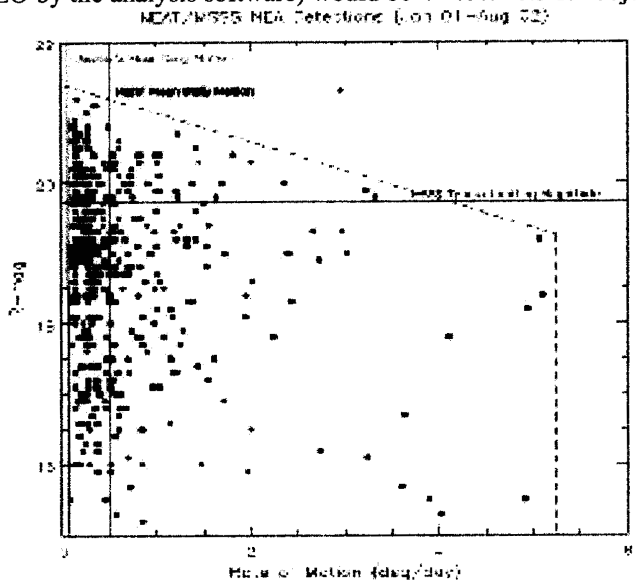

Fig. 1: Visual magnitude vs. rate of motion at the time of detection. The solid curve illustrates the detection limit for NEAT/MSSS under a typical limiting magnitude of 19.7. The dotted sloped line indicates the variation of limiting magnitude with degrees of motion under exceptionally good seeing conditions. The vertical blue line indicates the mean daily motion of Mars.

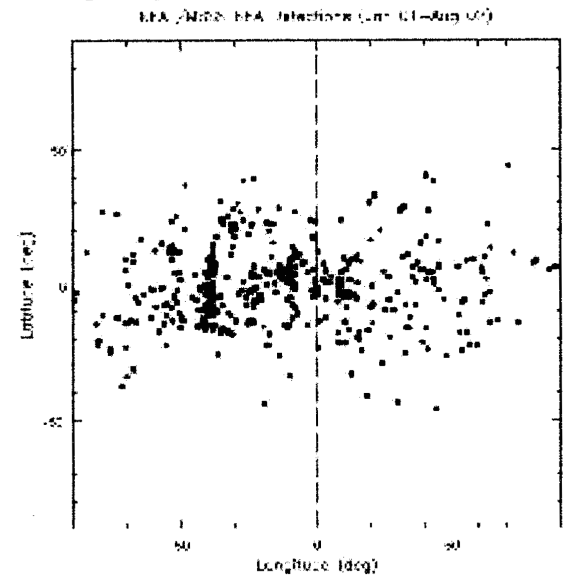

Fig. 2: Ecliptic longitude and latitude of MSSS NEA detections. NEAT/MSSS searches ±25 degrees above and below the ecliptic.

modest improvement over NEAT incarnation at the GEODDS 1.0-m, which had a detection limit of 19.1 [8]. The position in the sky with respect to the opposition point for all NEAT/MSSS NEO detections is given in Fig. 2. Note that objects are fairly randomly distributed around the ecliptic, before and after opposition. This is an improvement over last year's report where most discoveries were closer to ±30 degrees of opposition. Last year we reported a bias toward the discovery near opposition where NEO rates of motions are generally more distinguished from main-belt objects. This may be due to the fact that we routinely now search with 20-second exposures rather than 60-seconds. Re-examination of Fig 1 shows a significant discovery rate of NEOs at main-belt rates by the large number of discoveries between the Mars and Jupiter mean daily motions.

There are detections limits imposed by the analysis software, which is sensitive to asteroids moving up to 5.6 degrees per day. Objects also must have a motion greater than 2 pixels between adjacent frames in the triplet, giving rise to a minimum rate of motion of approximately 0.09 degree per day. A consequence of this is that our analysis software will not flag objects moving at Kuiper Belt rates. We have implemented a distant object search using search fields imaged on weekly time scales, as developed by Larson, et al. [11] although this is not a standard mode of operation of NEAT/MSSS.

NEAT/MSSS has the ability to search approximately 55 degrees per hour with 20 sec exposures which extrapolates to 15,000 degrees per month under ideal conditions. The actual sky coverage is a function of weather and the fraction of the month dedicated to NEO observations but we have maintained a schedule of approximately 8000 degrees per month since early 2001.

## 8. Further Optimization

An extended baffle, to mitigate stray light and internal reflections from bright off-axis stars in the telescope optics was installed on NEATA/MSSS this last year. Consequently, although we have reduced exposures to 20 seconds we are detecting fainter objects and minimizing false detections. Further work is planned for the mount control software. As a result, we expect faster telescope slew rates, expanded sky coverage and the ability to reach presently inaccessible parts of the sky. Plans are also underway to secure an improved CCD chip. As these improvements are implemented, AFRL will certify the system, as required by SPCMD, for satellite observations. Continuing improvements in the analysis software are being addressed, particularly in the area of post-processing.

## 9. Near-Earth Asteroids

The first asteroid, Ceres, was discovered by Piazzi in Palermo, Italy on January 1, 1801. The discovery came as a result of a prediction of the Titius-Bode law that there was a missing planet at approximately 2.8 AU from the sun, or between the orbits of Mars and Jupiter. The Titius-Bode equation, $R=0.4 + 0.3 * 2^n$, where R is the radius from the sun in AU and where n is an integer, from 0 upward, was a fairly accurate relationship for predicting the orbits of all the known planets in the 1700's except for n = 4. When Uranus was discovered in 1781, its distance was remarkably close to the value predicted by the equation where n = 7. This caused a systematic search for the planet at n=4 that resulted in the discovery of Ceres.

Tens of thousands of these bodies have now been found, but only about 100 are larger than 100 km. In 1881, the first Near-Earth Asteroid, 433 Eros, was found. As of September 1, 2002, nearly 2000 Near-Earth Asteroids have been detected as shown in Table 1 which summarizes the discoveries of all NEA searches [12].

Near-Earth Asteroids fall into 3 classes, or families, based on orbital dynamics (ephemerides) considerations: Atens, Apollos and Amors [13]. These names are approximately related to the first named body that defines the ephemerides. Fig. 3 shows a plot of the orbital characteristics of these 3 families and Table 1 shows the numbers discovered for each of these classes vs. time. As can be seen an NEA is an asteroid that comes within 0.3 AU of earth's orbit plane. However, for the purpose of the NASA NEO program, the NEAs of interest are those having a diameter greater than 1 km. In Table 1 those objects are shown under the heading of NEA+18. If the asteroid's orbit passes within an 0.05 AU torus around earth's orbit, and has a diameter of 100 meters or more, then that NEA is called a Potentially Hazardous Asteroid (PHA). We know of 459 of these objects. Of those 459, 121 have a diameter greater than 1 km as shown under column PHA+18.

Table 1. Near Earth Object Statistics for Selected Years [12]

| Date | NEC | Aten | Apollo | Amor | PHA+18 | PHA | NEA+18 | NEA | NEO |
|---|---|---|---|---|---|---|---|---|---|
| 2002-09-14 | 46 | 159 | 1014 | 836 | 121 | 459 | 618 | 2009 | 2055 |
| 2002-09-01 | 46 | 157 | 1002 | 824 | 121 | 457 | 612 | 1983 | 2029 |
| 2001-08-01 | 43 | 111 | 700 | 601 | 97 | 332 | 495 | 1412 | 1455 |
| 1998-01-01 | 38 | 27 | 233 | 186 | 49 | 108 | 221 | 446 | 484 |
| 1996-01-01 | 38 | 21 | 175 | 151 | 43 | 86 | 198 | 347 | 385 |
| 1970-01-01 | 29 | 1 | 13 | 14 | 8 | 11 | 24 | 28 | 57 |
| 1900-01-01 | 17 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 18 |

NEC = Near Earth Comets
PHA = Potentially Hazardous Asteroid
PHA+18 = Potentially Hazardous Asteroid > 1 km
NEA+18 = Near Earth Asteroid > 1 km
NEO = Total of all Near Earth Objects

## 10. NEO Size Distribution

The discovery statistics of an automated NEO detection program can be used to constrain size and orbit-dependent trends within the NEO population. Recently, Rabinowitz, et al., [14] analyzed NEAT data obtained

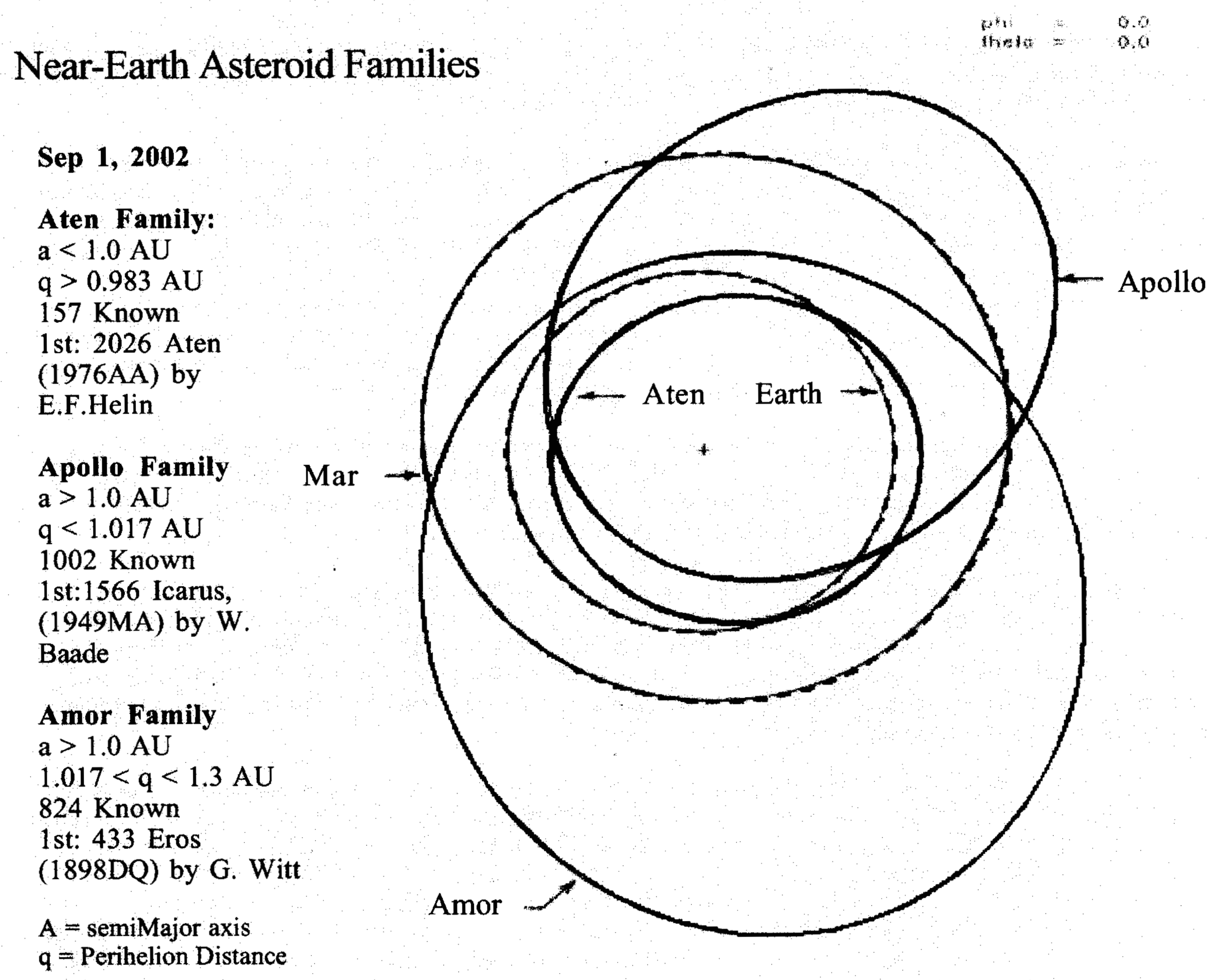


Fig 3. Orbit plots of Near-Earth Asteroid Families

between March, 1996 to August, 1998. This represents approximately 35,000 square degrees of sky. He derived a new estimate of the number of kilometer-sized near-Earth asteroids to be 700±230. This was significantly less than other estimates [15][16]. The sum total now discovered is 618 with 6 years left on the program. Such estimates will be significantly refined in the near future with the analysis of the more recent and complete NEAT/MSSS data.

## 11. Discussion of Recent Discoveries

Cumulative results from the start of NEAT/MSSS in March, 2000 through August, 2002 indicate 64 NEAs, with 16 larger than 1 km in diameter and 11 classified as potentially hazardous asteroids (PHAs). Total NEA detections over this time period which include previously discovered objects amounts to 242 with 142 larger than 1 km. Table 3 gives a complete listing of NEAT/MSSS NEA discoveries for the past 30 months. The following discussion is a review of some of the more interesting NEO discoveries made by NEAT/MSSS and illustrate the diversity of objects found by the search program.

The program's first discovery, 2000 ES70 was found on the second full day of observations and is a large, highly inclined Amor asteroid. Illustrating the synergy between the two NEAT observing sites, 2001 PJ is a small, Earth-grazing asteroid. A small number of NEOs cross deeply into the inner solar system (e.g., 3200 Phaethon). On April 30 2001, NEAT discovered 2000 HD24, a 1 km Apollo asteroid with a Venus-crossing orbit.

NEAT/MSSS has discovered 16 potentially hazardous asteroids, marked as PHA in Table 3. At least 3 of the objects will have spectacular apparitions in the not distant future, including 0.028 AU for 2000 QW7 in 2087, 0.030 AU for 2000 YV137 in 2167, and 0.032 AU for 2000 YF29 in 2136.

A useful by-product of the automated NEO search programs is the discovery of other classes of small solar system bodies. With the exception of the faint Kuiper Belt objects and the SOHO sun-grazing comets, these search programs have been the primary source of all new bodies, including main-belt asteroids, Centaurs, and comets. Over 170,000 asteroid detections have been submitted to the MPC by NEAT/MSSS in the past 30 months. More interesting are the nine new NEAT/MSSS comets, as listed in Table 2. Five of these objects are periodic comets, with Jupiter-crossing orbits, which bring them into the inner solar system. Four are non-periodic comets with two (C/2001 B2 and C/2001 O2) having perihelion points outside the orbit of Jupiter. These latter two objects are most likely recently perturbed from the Oort Cloud. Their strong activity at such large heliocentric distances must be powered by the sublimation of ices more volatile than water, such as C0, CO2, and/or N2.

The NEAT/MSSS search for near-Earth objects can yield asteroids with orbits indistinguishable from Jupiter Family Comets, such as 2000 GH147, 2000 WX28, 2001 FF90, and 2001 OK17. These asteroids are likely the devolatilized cores of inactive comets and such objects shall prove invaluable in the understanding of the evolution of comets into asteroids and the true nature of the NEO population.

It is important to stress that most of our comets were discovered in the visual examination of the main-belt detections. Because we visually inspect each detection that the software flags, we are able to detect comets moving at main-belt rates of motion. This visual verification is quite time consuming but it is presently the best way to distinguish from the asteroids discovered by the automated detection algorithms. The tool by which this is done, patchview, is illustrated for comet 2002 K4 in Fig 4. The images in the nine "patches" illustrate how a faint comet appears to the observer screening the detections.

The 3 comets discovered in 2002 illustrate extremes of comet orbits and detection challenges. Comet 2002 K1, discovered on May 16, 2002 is a highly-inclined (88.2°) parabolic comet whose perihelion is between Mars and Jupiter. Its V magnitude of 19.6, at discovery, was near the limiting magnitude of the NEAT/MSSS system, especially with a motion of 1.62 degrees per day. Comet 2002 O5, discovered July 30, 2002, is an earth-approaching (Perihelion 1.17 AU) short 4.87-year periodic comet with its aphelion out near Jupiter. Most interesting, however, is Comet 2002 K4, discovered on May 27, 2002. It is a periodic comet whose perihelion lies outside the orbit of Mars but it has a period of 73.4 years. Its V magnitude at discovery was 18.5 and its motion per day was 0.43 degrees, i.e., at main-belt rates (Fig 4), although it is in a retrograde orbit at an inclination of 95.5°. Its similarity to the more earth-approaching Comet Halley is striking when their orbits are overlaid in Fig 5.

## 12. Physical Studies of MSSS Asteroids

By increasing the number of known Near-Earth asteroids, NEAT/MSSS has greatly facilitated physical studies of this important class of solar system objects, especially the very small and fast moving objects which tend to quickly fade after discovery. Several of the recent close-approaching MSSS asteroids have been imaged by JPL's Planetary Radar team lead by Steve Ostro, including 2000 QW7, 2000 YF29 and 2001 EC16. One of the co-authors (Hicks) [17] maintains an active program of photometric follow-up of NEOs at the JPL Table Mountain Observatory with the emphasis on possible radar targets. For example, he has obtained B-R, V-R, and I-R colors of both 2000 QW7 and 2000 YF29. The spectral properties of near-Earth asteroids are diverse, with the colors of 2000 QW7 and 2000 YF29 consistent with a Q-type and D-type classifications, respectively.

## 13. Multiple Use of NEAT/MSSS Archived Data: *SkyMorph*

NEAT data are archived within days of receipt via the *SkyMorph* program. *SkyMorph* is funded by NASA's Applied Information Systems Research Program under the lead of S. Pravdo and provides a publicly-accessible WWW site (http://skys.gsfc.nasa.gov/skymorph/skymorph.html) for NEAT images and object information. The existing SkyMorph archive has already proven to be a major asset to the astronomy community. It is used for purposes as diverse as refining asteroid orbits and discovering supernovae. These data cover the dimension of time in a way that is unique among large optical databases: most of the sky is re-observed with the same instrument on time scales from hours and months to years.

Pre-discoveries enable moderate and long-term extrapolations of NEO orbits both for space mission rendezvous planning and for hazard-to-the-Earth evaluation. A pre-discovery can extend the temporal baseline (data arc) by years without the necessity for new observations of the object in question. A reason for non-detection of an asteroid in standard NEAT processing is that the object was not identified in *all* of the three triplet images, because, for example, it overlaid a star in one image. Even the relatively short baseline of NEAT, of about 6.5 years, has resulted in many pre-discoveries. Approximately 50 pre-discoveries of asteroids per month are reported to the Minor Planet Center (MPC) using archived NEAT data.

## 14. Summary

JPL has had a long successful collaboration with the AMOS/MSSS, extending back to 1993 for follow-up operations with the AMOS 1.6-meter telescope and December, 1995 for the NEAT/GEODSS program. The dual use of the NEAT camera as both a discovery/survey instrument as well as satellite detection system serves NASA's goal of detecting NEOs greater than 1-km as well as the Air Force satellite-tracking mission. NEAT/MSSS, along with NEAT/Palomar, was the dominant source of NEAs and comet discoveries in August, 2002.

## 15. Acknowledgments

Observations made at the Maui Space Surveillance System (MSSS), Maui, Hawaii, USA are the result of collaboration between NASA/JPL/Caltech and Detachment 15 of the U. S. Air Force Research Laboratory, which owns and operates the MSSS. We wish to acknowledge and thank Paul Kervin, John Africano, Paul Sydney, Riki Maeda, and other staff without which NEAT/MSSS would not exist, as well as the generous support by the Air Force. The research described in this paper, was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Table 2: COMETS DISCOVERED BY NEAT/MSSS MARCH 2000 - 31 AUGUST 2002

| NEAT/MSSS | Discovery Date | Motion | V Mag | a | e | i | q | MPC/Ref. |
|---|---|---|---|---|---|---|---|---|
| 2001 | | | | | | | | |
| C/2001 B2 (NEAT) | 1/24 | 0.22 | 15.5 | ---- | 1.00 | 150.60 | 5.306 | 42665 |
| P/2001 BB50 (LINEAR-NEAT) | 3/20 | 0.13 | 18.4 | 5.68 | 0.59 | 10.62 | 2.347 | 42665 |
| P/2001 F1 (NEAT) | 3/24* | 0.14 | 19.7 | 6.45 | 0.36 | 19.09 | 4.153 | 42856 |
| P/2001 J1 (NEAT) | 5/11 | 1.21 | 19.9 | 3.88 | 0.76 | 10.16 | 0.937 | 42856 |
| P/2001 K1 (NEAT) | 5/20* | 0.21 | 18.7 | 3.85 | 0.36 | 16.91 | 2.469 | 42856 |
| C/2001 O2 (NEAT) | 7/25* | 0.14 | 19.3 | ---- | 1.00 | 101.12 | 6.818 | 43161 |
| 2002 | | | | | | | | |
| C/2002 K1 (NEAT) | 5/16 | 0.32 | 19.6 | ---- | 1.00 | 88.22 | 3.243 | MPEC 02-K17 |
| C/2002 K4 (NEAT) | 5/27 | 0.41 | 18.5 | ---- | 1.00 | 95.94 | 2.742 | MPEC 02-K69 |
| P/2002 O5 (NEAT) | 7/30 | 1.36 | 17.2 | 2.87 | 0.59 | 20.3 | 1.173 | MPEC 02-P19 |
| * Discovered within Main-belt data. | | | | | | | | |

**Table 3: NEAs DISCOVERED BY NEAT/MSSS MARCH 2000 - 31 AUGUST 2002**

| Desig. | NEATID | Disc. Date | Circumstances Motion | V | Orbital Elements a | e | i | H | q | MPEC |
|---|---|---|---|---|---|---|---|---|---|---|
| 2000 ES70 | JBHTAT | 03/10 | 0.90 | 17.8 | 1.80 | 0.32 | 25.2 | 17.1 | 1.228 | 2000-E53 |
| 2000 HD24 | JTRTZG | 04/30 | 1.26 | 18.2 | 1.34 | 0.62 | 9.47 | 17.8 | 0.511 | 2000-J12 |
| 2000 PN8 | KTI8QF | 08/05 | 3.26 | 20.9 | 1.25 | 0.22 | 22.34 | 22.1 | 0.980 | 2000-P45 |
| 2000 QW7 | L10QUN | 08/26 | 3.98 | 13.6 | 1.95 | 0.47 | 4.17 | 19.5 | 1.035 | PHA 00-Q32 |
| 2000 SD8 | LA2364 | 09/20 | 0.94 | 19.7 | 1.13 | 0.32 | 6.64 | 20.7 | 0.774 | 2000-S40 |
| 2000 SE8 | LA3EUM | 09/20 | 2.54 | 18.5 | 2.51 | 0.59 | 0.65 | 23.4 | 1.017 | 2000-S41 |
| 2000 SQ43 | LBX1ER | 09/25 | 0.24 | 19.7 | 2.21 | 0.48 | 5.17 | 18.6 | 1.142 | 2000-S63 |
| 2000 SZ44 | LC8J4P | 09/26 | 0.65 | 19.8 | 2.51 | 0.52 | 5.79 | 20.5 | 1.207 | 2000-S69 |
| 2000 WX28 | LXI24S | 11/23 | 0.90 | 20.0 | 2.95 | 0.62 | 5.56 | 21.3 | 1.136 | 2000-W49 |
| 2000 WN107 | LZLNS5 | 11/29 | 0.32 | 19.4 | 1.55 | 0.42 | 13.32 | 16.3 | 0.904 | 2000-X09 |
| 2000 XF44 | M1QMNC | 12/04 | 2.23 | 19.7 | 2.50 | 0.56 | 13.14 | 21.1 | 1.101 | 2000-X30 |
| 2000 YF29 | M9Q2AA | 12/26 | 0.56 | 18.0 | 1.49 | 0.37 | 6.29 | 20.2 | 0.938 | PHA 01-A04 |
| 2000 YK29 | M90PLN | 12/24 | 0.64 | 17.1 | 1.38 | 0.13 | 15.22 | 18.1 | 1.200 | 2001-A08 |
| 2000 YL29 | M9QJJA | 12/26 | 0.18 | 20.6 | 1.55 | 0.33 | 21.54 | 15.7 | 1.042 | 2001-A09 |
| 2000 YV137 | MBJ7U8 | 12/31 | 0.47 | 20.2 | 1.39 | 0.15 | 23.06 | 17.9 | 1.185 | PHA 01-B22 |
| 2001 BJ16 | MI05VN | 01/18 | 0.65 | 18.8 | 1.39 | 0.15 | 23.06 | 17.9 | 1.185 | 2001-B33 |
| 2001 BZ39 | MIDP52 | 01/19 | 0.29 | 19.3 | 1.96 | 0.42 | 8.76 | 18.2 | 1.147 | 2001-B38 |
| 2001 BA40 | MJTC4D | 01/23 | 0.81 | 18.4 | 1.12 | 0.26 | 12.76 | 18.4 | 0.830 | 2001-B39 |
| 2001 DS8 | MSSR6U | 02/17 | 1.41 | 19.2 | 2.09 | 0.51 | 2.38 | 22.7 | 1.034 | 2001-D14 |
| 2001 EA16 | MZBHNW | 03/04 | 0.38 | 19.1 | 1.51 | 0.43 | 38.96 | 17.0 | 0.865 | 2001-F04 |
| 2001 EC16 | N39H5T | 03/15 | 1.47 | 16.0 | 1.35 | 0.36 | 4.79 | 22.3 | 0.856 | 2001-F07 |
| 2001 FP32 | N50HKK | 03/20 | 5.06 | 19.2 | 1.37 | 0.34 | 29.66 | 23.4 | 0.906 | 2001-F33 |
| 2001 FB90 | N5BCOC | 03/21 | 1.22 | 20.7 | 1.67 | 0.60 | 1.51 | 20.8 | 0.662 | PHA 01-F45 |
| 2001 FF90 | N769V2 | 03/26 | 0.55 | 20.2 | 2.61 | 0.63 | 23.65 | 16.6 | 0.956 | 2001-F49 |
| 2001 GS2 | NE2XE1 | 04/14 | 1.95 | 18.4 | 1.78 | 0.38 | 18.71 | 20.0 | 1.101 | 2001-H07 |
| 2001 HG31 | NHN4GG | 04/24 | 0.32 | 19.5 | 2.57 | 0.52 | 5.88 | 16.0 | 1.242 | 2001-H48 |
| 2001 JL1 | M03N44 | 05/11 | 0.57 | 18.7 | 2.57 | 0.53 | 27.01 | 16.6 | 1.210 | 2001-J29 |
| 2001 JM1 | NOGH48 | 05/12 | 4.02 | 15.3 | 1.46 | 0.31 | 17.04 | 19.0 | 1.006 | 2001-J30 |
| 2001 JW1 | NP84XD | 05/14 | 3.02 | 19.0 | 1.18 | 0.07 | 35.45 | 20.3 | 1.097 | 2001-K04 |
| 2001 KO2 | NRRF7F | 05/21 | 2.66 | 19.3 | 2.62 | 0.62 | 12.12 | 20.2 | 0.989 | 2001-K21 |
| 2001 KO41 | NSSQMF | 05/24 | 0.28 | 19.7 | 2.04 | 0.44 | 5.07 | 20.6 | 1.134 | 2001-K35 |
| 2001 KZ66 | NUJHOF | 05/29 | 0.28 | 19.9 | 1.66 | 0.43 | 14.51 | 16.4 | 0.949 | 2001-K51 |
| 2001 LF | NWFN2K | 06/03 | 0.94 | 19.0 | 1.80 | 0.34 | 17.99 | 17.2 | 1.195 | 2001-L26 |
| 2001 OT | OC8G2Y | 07/16 | 1.56 | 19.4 | 0.93 | 0.32 | 12.12 | 21.2 | 0.634 | 2001-O10 |
| 2001 OD3 | OC9XEE | 07/16 | 0.99 | 20.4 | 2.52 | 0.50 | 14.89 | 18.8 | 1.250 | 2001-O13 |
| 2001 OC36 | OFGI3B | 07/25 | 2.38 | 19.0 | 1.41 | 0.48 | 2.29 | 22.9 | 0.732 | 2001-O42 |
| 2001 PJ | OJ0IYB | 08/04 | 1.42 | 20.5 | 2.10 | 0.50 | 5.78 | 20.4 | 1.051 | 2001-P18 |
| 2001 PD1 | OJ32C4 | 08/04 | 0.73 | 19.7 | 2.09 | 0.43 | 5.73 | 18.6 | 1.200 | 2001-P24 |
| 2001 PE1 | OJR8MS | 08/07 | 0.30 | 19.4 | 2.78 | 0.60 | 3.45 | 18.5 | 1.121 | 2001-P25 |
| 2001 PT9 | OLNQ3I | 08/11 | 1.17 | 19.9 | 1.46 | 0.45 | 7.20 | 20.2 | 0.800 | PHA 01-P38 |
| 2001 PU9 | OLW3KD | 08/12 | 1.96 | 20.4 | 2.17 | 0.49 | 28.37 | 19.6 | 1.104 | 2001-P39 |
| 2001 PJ29 | ON3MTH | 08/15 | 1.90 | 20.3 | 1.45 | 0.39 | 6.68 | 22.6 | 0.880 | 2001-Q06 |
| 2001 QQ142 | OQON81 | 08/25 | 1.16 | 19.9 | 1.47 | 0.33 | 9.66 | 18.2 | 0.988 | PHA 01-Q52 |
| 2001 TE2 | P8AUPE | 10/12 | 0.73 | 20.1 | 1.08 | 0.20 | 7.62 | 20.0 | 0.870 | 2001-T55 |
| 2001 TE45 | P9DMI5 | 10/15 | 2.95 | 21.3 | 1.78 | 0.46 | 14.45 | 23.3 | 0.971 | 2001-U13 |
| 2001 UF18 | PDBWSB | 10/26 | 1.70 | 20.0 | 1.12 | 0.60 | 29.90 | 19.4 | 0.446 | 2001-U70 |
| 2001 WL15 | PNGQP1 | 11/23 | 1.21 | 19.2 | 2.11 | 0.50 | 7.13 | 18.3 | 1.050 | PHA 01-W64 |
| 2001 YV3 | PY7SW9 | 12/22 | 2.72 | 18.9 | 1.95 | 0.72 | 5.20 | 20.8 | 0.547 | PHA 01-Y38 |
| 2001 YJ4 | PY91YY | 12/22 | 0.63 | 19.3 | 2.62 | 0.61 | 9.63 | 15.9 | 1.021 | 2001-Y47 |
| 2001 YB5* | PZNMWG | 12/26 | 0.15 | 19.9 | 2.38 | 0.86 | 5.49 | 20.6 | 0.322 | PHA 01-Y51 |

* 2001 YB5 was discovered at MSSS, followed-up at Palomar on 27 Dec.
Discovery credit was given to Palomar by MPC.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2002 | AA2 | Q3WVEF | 01/07 | 4.94 | 18.2 | 2.28 | 0.53 | 35.16 | 20.2 | 1.069 | | 2002-A32 |
| 2002 | AD2 | Q407SG | 01/07 | 2.97 | 19.3 | 1.42 | 0.24 | 32.39 | 20.0 | 1.072 | | 2002-A35 |
| 2002 | AF29 | Q64GVB | 01/13 | 0.74 | 20.2 | 3.29 | 0.62 | 8.00 | 18.9 | 1.246 | | 2002-A94 |
| 2002 | AJ129 | Q6WSSL | 01/15 | 2.00 | 20.3 | 1.44 | 0.93 | 16.88 | 18.4 | 0.106 | PHA | 02-B14 |
| 2002 | CM1 | QDQ610 | 02/03 | 0.61 | 20.6 | 2.24 | 0.43 | 47.47 | 16.7 | 1.284 | | 2002-C23 |
| 2002 | CP4 | QE1ONL | 02/04 | 1.22 | 19.8 | 1.73 | 0.36 | 13.69 | 21.3 | 1.111 | | 2002-C25 |
| 2002 | CZ46 | QGLT39 | 02/11 | 0.44 | 20.3 | 1.69 | 0.32 | 16.37 | 17.9 | 1.153 | | 2002-C90 |
| 2002 | FG7 | QXWQD9 | 03/28 | 1.23 | 19.0 | 1.51 | 0.63 | 9.31 | 18.7 | 0.561 | PHA | 02-G03 |
| 2002 | FQ4 | QUOBSU | 03/19 | 1.45 | 20.3 | 2.08 | 0.38 | 44.35 | 19.6 | 1.290 | | 2002-F38 |
| 2002 | GJ1 | ROC9CU | 04/04 | 3.22 | 19.9 | 2.00 | 0.50 | 6.98 | 23.3 | 0.994 | | 2002-G24 |
| 2002 | KL6 | RJTH11 | 05/27 | 1.44 | 17.4 | 2.81 | 0.63 | 3.51 | 17.0 | 1.044 | | 2002-K70 |
| 2002 | LJ3 | RN40AT | 06/05 | 0.46 | 20.2 | 1.42 | 0.23 | 7.16 | 18.4 | 1.088 | | 2002-L26 |
| 2002 | LS24 | ROGQ85 | 06/09 | 1.63 | 19.8 | 2.27 | 0.56 | 8.36 | 22.1 | 1.011 | | 2002-L04 |
| 2002 | QZ6 | SDR39Q | 08/17 | 4.91 | 15.5 | 1.96 | 0.44 | 22.23 | 19.6 | 1.095 | | 2002-Q18 |

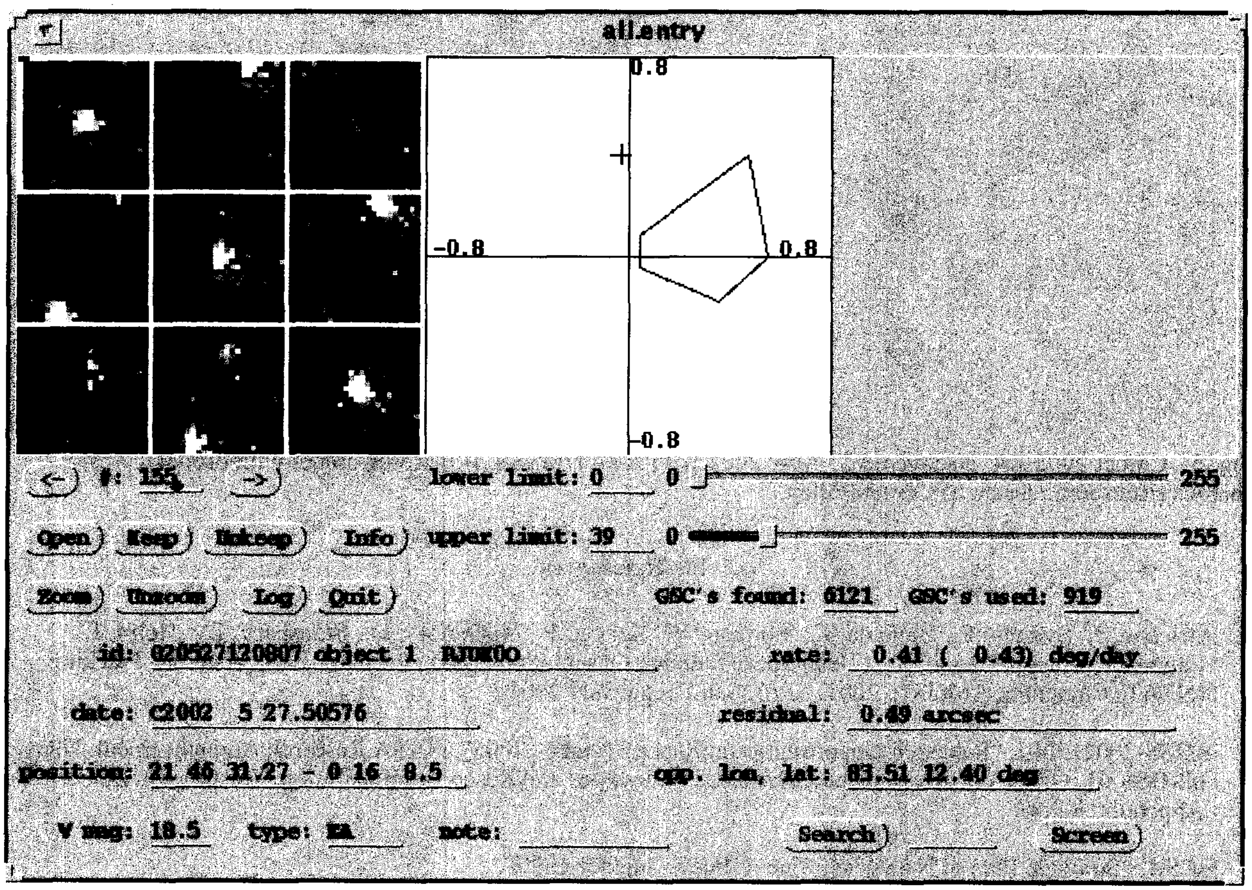


Fig 4. The patchview panel for Comet 2002 K4 discovered May 27, 2002

| | C/2002 K4 | 1P/Halley |
|---|---|---|
| Inclination: | 95.9 deg | 162.2 deg |
| Perihelion: | 2.7 AU | 0.59 AU |
| Period: | 73.4 years | 76.5 years |

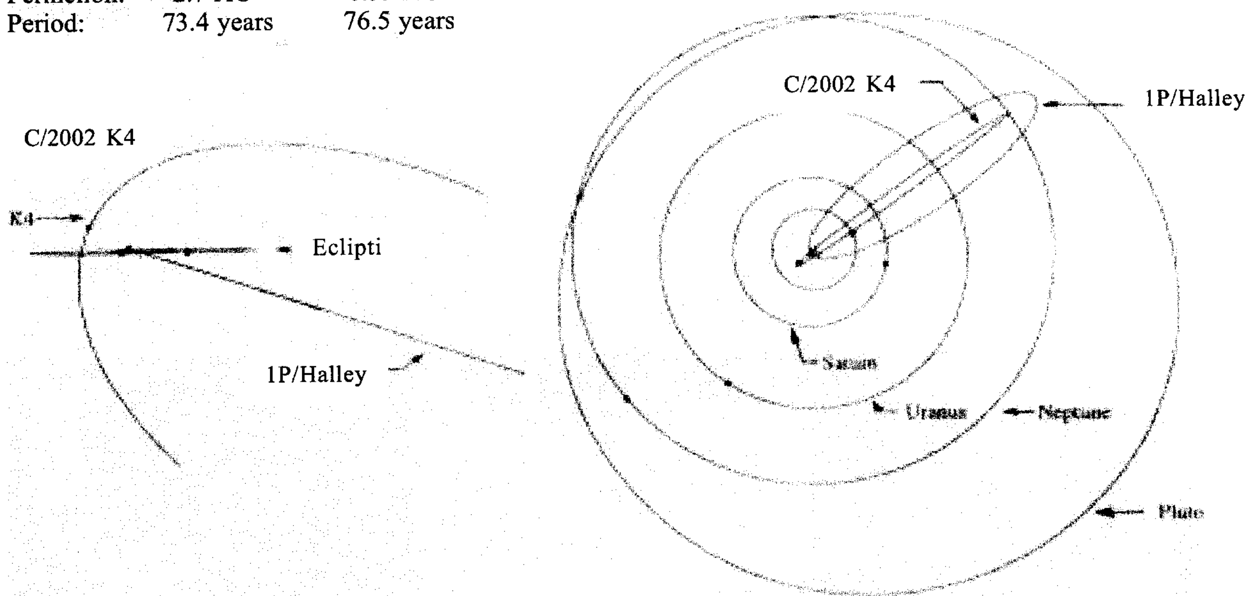


Fig. 5: Comet 2002 K4, discovered 27 May 2002 with NEAT/MSSS, is periodic comet with orbital characteristics reminiscent of Comet Halley.

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